

International Aspects of Public Goods Provision.

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Abstract.

This paper considers the extension of the theory of public consumption goods to an international context with public goods whose benefits are global. In one version of the model there are no restrictions on lump sum transfers within and between nations, and the Samuelson conditions for welfare maximization then hold for the world as a whole. However, in another version there are no income transfers between nations, and the conditions then have to be modified. In particular, it is shown that global production efficiency is not in general desirable in the absence of international transfers. Problems of national incentives and international implementation are also considered.

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1. Introduction.

The original contribution by Paul Samuelson to the analytical formulation of the theory of public goods (Samuelson 1954, 1955) contains few references to the jurisdictional framework in which decisions about public goods provision are assumed to take place¹. A natural interpretation is that what he primarily had in mind was the nation-state. But it is also a reasonable assumption that he saw the theory as being applicable to several types of jurisdictional frameworks. Such applications in later years have mainly been in the area of local public goods and local public finance. Only recently has the attention of economists been turned to global public goods, i.e. goods that are public in regard not only to the population of a particular country, but with respect to the world population as a whole; see Kaul et. al. (1999). The qualitative properties of the global environment offer perhaps the most obvious examples of such goods, but there are many others. Knowledge is an obvious and important example, while public health is another public good with important international dimensions. At the institutional level, important examples of global public goods are institutions required to promote world peace and international security or to sustain the global market economy.

The Samuelson formulation is cast in the framework of welfare economics. It postulates an individualistic welfare function which depends positively on the utility levels of the individual consumers in the economy, and the aim of the analysis is to characterize an optimal allocation of resources when social welfare is maximized subject to a production possibility constraint. The most novel result to emerge from the analysis was the famous ‘Samuelson rule’. This says that for the supply of public goods to be optimal, the sum of the marginal rates of substitution, taken over all consumers in society, between the public good in question and some *numéraire* private good, must be equal to the marginal rate of transformation in production. An alternative interpretation is that the aggregate marginal willingness to pay for the public good must equal its marginal cost of production.

The aim of the present paper is to consider the extension and interpretation of this theory to the context of global public goods. A focus of the discussion is the question of the validity of the Samuelson rule in a global context. Is this the way that we should think about the

¹ For an exposition of the Samuelson model and a short survey of some of the subsequent literature see Sandmo (1987).

provision of global public goods? If not, what are the changes or modifications needed before the theory can be applied to this type of public good? It will be shown that the most problematic part of the extension concerns the desirability of global production efficiency and the separation of equity and efficiency conditions which play such an important role in the Samuelson formulation.

The emphasis in the paper is on normative theory in the welfare economics sense, although some discussion of implementation and incentives is included, particularly in Section 7. An alternative would have been to approach the problem from a positive angle: What is the nature of an equilibrium with global public goods that emerges from voluntary cooperation between a number of countries? A formal analysis of this problem had best be left for separate treatment. However, since an important focus of a positive theory would be the efficiency properties of the equilibrium, the normative theory provides an important benchmark for such a study².

2. Sources of public goods provision.

Some of Samuelson's examples of pure public goods were "an outdoor circus or national defense" (Samuelson 1955). Apart from their tongue-in-cheek nature, these are examples where we are led to think of the goods being provided by explicit choice of some well-defined decision maker, but for many public goods this is a simplified picture. Whether we think of the natural or the cultural environment, it is clear that at any point in time these goods are partly determined by exogenous forces; they are given by the laws of nature or by human activities of the past. Their current and future availability is also determined by the actions of a large number of consumers and producers. The effects of these actions are sometimes negative, as when private agents contribute to climate gas emissions, traffic congestion or the degradation of historical monuments due to air pollution. In other cases they are positive, e.g. when private spending on architectural design contributes to the aesthetic value of the cultural landscape. In addition, availability is also determined by public actions. The public provision of such goods will therefore take both direct and indirect forms. When we think of the producers or providers of public goods, we must accordingly have a flexible interpretation of who these may be. In some cases they are individual consumers or producers who contribute

to the availability of the public good as a by-product of other activities. In other cases they are public or private agencies that make explicit budgetary decisions to increase the provision of public goods. These may take the form of explicit funding or the introduction of policies designed to modify the actions of private individuals.

The effects of individual production and consumption decisions on the quantity and quality of public goods are of course what is known as externalities. There is a large literature on how governments can improve the functioning of private markets when private goods have public goods-type externalities; see e.g. Sandmo (2000) for a more detailed discussion. In the following I shall not attempt to introduce a careful distinction between the cases of pure public goods and private goods with externalities, but mostly limit myself to the former case. This is not as restrictive as it may seem, for many of the problems that arise in this area, like the choice of method for the revelation of willingness to pay, turn out in fact to be of exactly the same nature in the two cases.

3. A model of resource allocation: Basic assumptions.

The notion of a social welfare function, so central to the Samuelson theory of public goods, is viewed by many with a good deal of scepticism. The scepticism stems partly from the Arrow impossibility theorem (Arrow 1951), partly from the criticism by Buchanan³ and others of the public choice school that the very notion of an aggregate social welfare function is inconsistent with the values of a democratic society. The scepticism would seem to apply *a fortiori* to the notion of a global social welfare function, which, nevertheless, will be used below. I should stress, therefore, that my use of this concept does not in any way deny the force of the Arrow theorem. It is not meant to imply the existence of a political system of global preference aggregation, nor that there is a benevolent global planner who manages the world's resources according to his ethical values. The role of the social welfare function in the following is just to help us understand the limited significance of *social efficiency* or Pareto optimality as the sole guide to rational decisions. Thereby it also helps us to understand the dividing line between efficiency criteria on the one hand and ethical judgements on the other.

² The treatment of this problem would have to draw on the literature on the private provision of public goods. For a good introduction to this literature, see Oakland (1987, Section 4), as well as Cornes and Sandler (1996).

³ A selection of Buchanan's writings in this area is in Buchanan (1987).

For simplicity, I assume that the world can be thought of as having two countries, one rich and one poor. The rich country consists of n consumers with utility functions u^{iR} , where $i=1, \dots, n$. Similarly, the m consumers of the poor country have utility functions u^{jP} . For simplicity I assume that there is just one private and one (global) public good, so that the utility functions can be written as

$$u^{iR} = u^{iR}(x^{iR}, g); i = 1, \dots, n, \text{ and } u^{jP} = u^{jP}(x^{jP}, g); j = 1, \dots, m. \quad (1)$$

Here x^{iR} is the private good consumption of the i 'th individual in the rich country, and x^{jP} has a corresponding interpretation. The global public good g enters into all utility functions, but the subjective valuations of the good may differ between individuals. It is likely to differ between the rich and the poor country, but also within the populations of the two countries.

The public good, as it is modelled here, is a *pure public good* in the Samuelson sense. It is public both within and between the two countries. The enjoyment of the good by citizen i in country R does not diminish its availability for citizen j in country P . This type of public good is a polar case which allows us to focus on the problem of global public goods in its purest form. However, there are clearly a number of alternatives for theoretical modelling that have a higher claim to descriptive realism. Air pollution may travel to other countries but still affect the country of origin more severely; absence of air pollution in this case is therefore a mixture of a national and a global public good. Moreover, since air pollution is mainly generated as a by-product of the consumption and production of private goods, it may also be treated as a case of private goods use with both national and international external effects. Such cases are discussed in more detail in the article by Sandler in this volume. The present focus on pure public goods is motivated, first, by the desire to provide a direct extension of the Samuelson model to a global context, and, second, to study the problem of incentives in a setting that is directly comparable to the original formulation of the theory.

The social welfare function is then

$$W = W(u^{1R}, \dots, u^{nR}; u^{1P}, \dots, u^{mP}). \quad (2)$$

Note that the maximum of the social welfare function (subject to the production possibilities constraint) is necessarily also a Pareto optimum. For if we have an allocation where we can

make one consumer, e.g. the poorest individual in the poor country, better off without making anyone else worse off, the value of the social welfare function must increase. Therefore, such an allocation cannot be a welfare maximum.

The description of the production side of the economy proceeds in two steps. On the one hand it is assumed that both countries devote some of their resources to provide the global public good, and that the global provision is an increasing function of the individual countries' contribution. In general, this can be written as

$$g = \mathbf{j}(g^R, g^P). \quad (3)$$

For simplicity of exposition, in the following I shall use the more specific assumption that

$$g = g^R + g^P. \quad (3')$$

The special assumption that the amount of global public good is equal to the sum of individual countries' contributions is one that in this particular context must mainly be justified in terms of analytical simplicity. More generally, it is reasonable to assume that the different countries' contribution may have a different degree of efficiency in contributing to the global public good⁴. But at the present level of abstraction the special assumption does not detract from the general validity of the conclusions that can be drawn.

Each of the countries is constrained in its output of private and public goods by technology and factor supplies, and these constraints are summarized as

$$F^R(x^R, g^R) = 0, \text{ and } F^P(x^P, g^P) = 0. \quad (4)$$

Here x^R and x^P are the aggregate quantities of private goods produced and consumed in the rich and the poor country, respectively, so that $\mathbf{S}_i x^{iR} = x^R$ and $\mathbf{S}_j x^{jP} = x^P$.

⁴ In theories of externalities and public goods several alternative assumptions have been explored concerning the relationship between individual contributions and the aggregate outcome, of which the case represented by (3') is clearly a special although important one. Cornes and Sandler (1996), who survey a number of alternative models, refer to the present case as that of a 'summation technology'.

The equations (4) give us, for each country, the maximum amount of contribution to the global public good that can be achieved for any given amount of private good consumption. Behind the efficiency frontier, which is assumed to have the usual concavity properties, lie a number of assumption about the efficient allocation of factors of production among sub-sectors of the economy, but for reasons of space these will not be discussed explicitly here. In order to facilitate an intuitive interpretation of the results, in the following I will use the quasi-linear forms

$$x^R + C^R(g^R) - R^R = 0, \text{ and } x^P + C^P(g^P) - R^P = 0. \quad (4')$$

Here R^R and R^P are constants representing the resource limitations of the two economies. The functions C^R and C^P are assumed to be continuous with positive first and second derivatives. This ensures that the production possibility curves have the usual properties. Moreover, the marginal rates of transformation, which in general should be written as F_g^R/F_x^R and F_g^P/F_x^P now become simply C_g^R and C_g^P . (Here and elsewhere subscripts will be used to denote partial derivatives in a notation that should otherwise be self-explanatory.) The latter expressions have an obvious interpretation as the marginal cost of producing the public good in terms of the quantity of private goods foregone.

Formally, the main difference between the present formulation and the standard one lies in the disaggregated treatment of the production side. It is obviously reasonable to assume that factor supplies and technologies differ between rich and poor countries, and even more reason than in a single-country analysis to be explicit about the conditions for productive efficiency.

4. Production efficiency.

As a step towards solving the global welfare maximization problem it is accordingly useful to examine the more limited issue of world production efficiency. A global allocation of resources in this context can be said to be productively efficient if, for some given total of the world's consumption of private goods, the provision of the global public good is at its maximum. This is obviously desirable in view of the wider objective of global welfare maximization, for in the absence of production efficiency it would have been possible to reallocate the world's resources so as to have more of the public good without suffering a loss

of private goods output. Such a reallocation would have the potential to improve the standard of living for all.

Formally, the problem of characterizing production efficiency can be set up as

$$\text{Maximize } g \text{ subject to } x^R + x^P = x^0, \quad (5)$$

where x^0 is some given amount of world consumption of the private good. Using equations (4'), production efficiency can be characterized by these and the condition

$$C_g^R = C_g^P. \quad (6)$$

This condition says simply that for global production efficiency to hold, the marginal cost of producing the global public good must be the same in rich and poor countries. In other words, comparative advantage should be fully exploited. The country in which factor endowments and technology make it cheaper to produce the public good, should devote more resources to it.

It is worth noting briefly at this point that if we had adopted the more general contribution technology (3) instead of (3'), condition (6) would have become

$$C_g^R/C_g^P = j_R/j_G, \quad (6')$$

where j_R and j_G are the partial derivatives of the function j . The ratio of marginal costs of production should be equal to the ratio of contribution efficiencies. This involves a more complex notion of comparative advantage, which should be kept in mind in the interpretation of the results based on the simpler case (3'). Comparative advantage is determined not only by relative production costs, but also by the relative efficiency with which countries contribute to the global public good.

The flavour of the production efficiency result is strongly reminiscent of a classic insight from the Heckscher-Ohlin version of theory of international trade, where the exploitation of

comparative advantage assures global production efficiency⁵. In that theory the next step is to show that free international trade will establish relative producer prices that are uniform across countries. Since, in a competitive equilibrium, these will be equated to the marginal rate of substitution in each country, it follows that free trade will result in an efficient allocation of production between countries. But international trade theory is almost exclusively about trade in private goods. It is interesting to ask under what institutional conditions a similar result can be expected to emerge in the context of public goods, and this will be considered further below.

Is global production efficiency necessarily desirable? Welfare economics has taught us to think that production efficiency is necessary for social welfare maximization; if some outputs can be increased with no decrease of other outputs, it must be possible to make it better for some consumers without making it worse for others. But in an international context it is not clear that this argument can be applied. The setup of the efficiency problem (5) assumes implicitly that world output of the private good is available to satisfy consumer needs in both countries; if, instead, national consumption possibilities are constrained by national output, the present formulation of the problem loses much of its appeal. These issues can only be clarified by embedding the production efficiency problem in the wider framework of welfare maximization.

5. Global welfare maximization.

We now consider the more general problem of global welfare maximization. This will be conceived as the maximization of the social welfare function (2) subject to the technological constraints (3') and (4'). In addition, we need to specify the connection between world consumption and world production. To begin with, we assume simply that world consumption must equal world production, so that

$$\mathbf{S}_i x^{iR} + \mathbf{S}_j x^{jP} = x^R + x^P. \quad (7)$$

Solving this problem of constrained optimization we obtain the following three sets of optimum conditions:

⁵ This must be understood as relative to the assumption that factors of production are internationally immobile.

$$C_g^R = C_g^P \bullet C_g. \quad (8)$$

$$S_i(u_g^{iR}/u_x^{iR}) + S_j(u_g^{jP}/u_x^{jP}) = C_g. \quad (9)$$

$$W_{iR} u_x^{iR} = W_{jP} u_x^{jP} \quad (i=1, \dots, n; j=1, \dots, m) \quad (10)$$

Equation (8) is the condition for global production efficiency (6), restated here for convenience. This condition ensures that the marginal cost of the public good - the opportunity cost of public goods provision in terms of private goods output - is the same in both countries. For convenience, this common value will be written as C_g . Equation (9) is a direct generalization of the Samuelson efficiency condition for public goods: The sum of the marginal rates of substitution between the public and private good - the sum of the corresponding sums for each of the countries - should be equal to the global marginal rate of transformation. Another way to write this condition is as the requirement that the marginal benefit-cost ratio - the ratio of marginal benefits to marginal costs - should be equal to unity, i.e.

$$[S_i(u_g^{iR}/u_x^{iR}) + S_j(u_g^{jP}/u_x^{jP})]/C_g = 1. \quad (9')$$

Finally, the set of equations (10) is a requirement that the marginal utility of private goods consumption be the same both for all consumers in each of the countries *and* across countries. Together, (8)-(10) constitute a complete characterization of the conditions for an optimal world allocation of resources. While conditions (8) and (9) are characterizations of efficiency or Pareto optimality, (10) characterizes the just or equitable distribution of resources between individuals.

At this point the generalization of the Samuelson analysis to an international setting may seem to be straightforward. In particular, the condition for optimal provision of public goods has the same form as in the original model, except for the splitting up of the sum on the left-hand side into one sum for each country. At the level of utopian thinking about world welfare, this may not be very surprising. However, as indicated above, the results are based on the assumption that private goods consumption in each of the two countries is only constrained by

world output, not by the level of output in the country itself. This may be too utopian to be helpful. It is true that international trade allows countries to choose consumption patterns outside their sets of production possibilities, but the assumption here is stronger than that. Since the single private commodity x represents the aggregate of all private consumption goods, national consumption can only differ from national production in the case where there exist transfers of consumption or income between countries, and it is this feature of the analysis that leads to the equity conditions (10). In other words, the constraint (7) is equivalent to an assumption of lump sum transfers not only within each country but also between countries, and it is this assumption that allows the neat separation of efficiency and equity considerations in the optimal solution. This is exactly similar to the Samuelson analysis. Implicit in the formulation is also the requirement that the net revenue from the transfers must be positive and equal to the resource cost of public goods provision.

Transfers of this kind should not be ruled out as irrelevant and uninteresting. The amount of foreign aid and development assistance is significant and could be increased further; moreover, as will be discussed further below, some transfers could be seen as payments for public goods supply. Nevertheless, it is also true that most countries in the main have to rely on their own resources, and it is therefore of obvious interest to examine the case where countries' consumption is constrained by their own output. This assumption can be represented by the two constraints

$$\mathbf{S}_i x^{iR} = x^R, \quad \mathbf{S}_j x^{jP} = x^P, \quad (11)$$

which should be compared with the single condition (7) for the previous case. It must be emphasized that (11) does *not* imply that there is no international trade. The single private good in this model should be interpreted as an aggregate of all private goods, and the assumption therefore means that the value of production must be equal to the value of consumption; in other words, trade must be balanced. By contrast, assumption (7) allows for the value of consumption in a single country to be either higher or lower than the value of production, and this can only happen through international transfers. Thus, both (7) and (11)

are consistent with an assumption of free trade; the difference between them is that (11) rules out international transfers.⁶

How does this change of assumption affect the case for production efficiency? First of all, it is worth emphasizing that the welfare case for *national* production efficiency remains valid. If one assumes the possibility of national lump-sum redistribution of income, it follows directly that the output of the private good should be maximized for any given level of public good contribution. In other words, national welfare can always be improved by moving from inside the production possibility frontier to some point on it.⁷ On the other hand, *global production efficiency is in general not desirable*. It is easy to see why. Assume that the two countries are initially in a situation where the marginal cost of the public good differs between them. Suppose that it is found that the concern for global production efficiency calls for the poor country to contribute more to the public good and for the rich country to contribute less. The poor country must then move along its production possibility frontier in the direction of less production of the private good, while the rich country will produce more. On average then, the poor country consumers must get less private goods consumption and the rich country consumers must get more. It is likely that this will involve a welfare loss, on the average, for consumers in the poor country⁸, and a corresponding gain to the rich country consumers. If the latter could transfer some of their gains to the former, everyone could gain, but it is precisely the inability to make these transfers that is implied by assumption (11).

Formally, the condition for optimal supply of public goods in this case can be written as

$$S_i(u_g^R/u_x^R)/C_g^R + S_j(u_g^P/u_x^P)/C_g^P = 1. \quad (12)$$

This equation should be compared with the corresponding equation (9') for the case when international transfers are possible; this says that the optimal provision of the global public good implies that the marginal benefit-cost ratio for the world as a whole must equal one. By

⁶ The formulation is similar to that in models of international trade with one traded and one non-traded good; for an exposition see e.g. Bruce and Purvis (1985), pp. 814-817.

⁷ Indeed, Diamond and Mirrlees (1971) showed that under certain conditions the case for production efficiency remains valid even when the only instruments for redistribution are distortionary taxes.

⁸ This will be true unless the poor country consumers have a much higher willingness to pay for the public good than consumers in the rich country.

contrast, (12) says that without transfers, it is *the sum of the national marginal benefit-cost ratios* that should equal one.⁹

While (9') represents an obvious extension of the theory of public goods to a global context, the interpretation of (12) is less obvious. A country's preferences for the global public good should count more in the evaluation of global benefits, the lower is its marginal cost of producing the good; in this way, the aggregation of preferences across countries take some account of production efficiency, which is intuitively reasonable.

But a puzzling feature of condition (12) is the apparent absence of welfare weights. Since there is no equalization of the social marginal utility of consumption between the rich and poor countries, one would expect the benefits to be weighted by terms that reflect the distributional preferences embedded in the social welfare function. Recall that we have assumed that there are perfect lump-sum transfers within but not between countries¹⁰. Consequently, the social marginal utility of consumption will be the same for all consumers in the poor country, and also between all consumers of the rich society. Formally, this can be written as

$$W_{iR} u_{ix}^R = g^R, \quad W_{jP} u_{jx}^P = g^P, \quad (i=1, \dots, n; j=1, \dots, m) \quad (13)$$

where g^R and g^P are the common social marginal utility of income for each of the two countries. From (12) the *relative* weight on the poor country's preferences is C_g^R / C_g^P . But from the solution to the optimization problem it follows, as demonstrated in the Appendix, that this is in fact equal to g^P / g^R , so that (12) has an alternative interpretation in terms of welfare weights. If the global welfare function has an egalitarian form, $g^P / g^R > 1$, and more weight is attached to the preferences of the poor population in deciding on the optimal provision of the global public good.

The connection between cost weights and welfare weights has an intuitive economic explanation. If the social welfare function has an egalitarian bias, so that more weight is attached to the private goods consumption of the poor country, one would like it to contribute

⁹ The derivation of equation (12) is shown in the appendix.

¹⁰ This is obviously not a realistic assumption. Its use here should be seen as an attempt to capture the idea that national redistribution policy is more highly developed than redistribution between countries.

less to the global public good. But since the marginal cost of providing the public good is increasing, this implies that the marginal cost in the poor country must, in an egalitarian optimum, be low compared to that of the rich country. The poor country should devote less resources to global public goods than indicated by considerations of comparative advantage.

An interesting question is whether the optimum without international transfers would entail a higher or lower solution value for the public good than the optimum solution when such transfers are possible. However, at the purely 'technological' level, abstracting from all incentive problems, no firm answer to this question can be given. Intuitively, whether a greater weight on the benefits derived by the poor country will increase or decrease the sum of marginal benefit-cost ratios, depends on whether the poor country's benefits are high or low compared to that of the rich country.

A natural extension of the present analysis would be to the case where countries must finance their expenditure on global public goods through distortionary taxes. In that case, countries' comparative advantage in the production of global public goods would be based not only on differences in marginal production costs but also on differences in the efficiency of their tax systems. However, such an extension of the literature on the marginal cost of public funds to an international context lies beyond the scope of the present paper and must be left for future research.

6. Problems of implementation: Cost efficiency.

The theory of public goods was originally formulated at a fairly high level of abstraction. Nevertheless, it has been remarkable in providing the theoretical foundations for applied cost-benefit analysis in a number of different areas. In cost-benefit analysis one considers a public project to be socially profitable if the aggregate benefits exceed the aggregate costs; for the "marginal" project, there should be equality between benefits and costs.¹¹ This criterion can be considered the practical interpretation of the optimality condition (9) or (9') in a national context. But we have seen that unless there is extensive international redistribution of income,

¹¹ The formal model considers the scale of a project to be continuously variable. This is an analytical simplification that does not fit all practical cases. Sometimes the choice is between carrying out a project on a given scale or not at all; on other occasions one has the choice between a few technologically feasible alternatives. In such cases the formal optimality criteria have to be restated in the form of inequalities, but I leave such complexities aside in order to focus on the basic economic insights that can be derived from the analysis.

global production efficiency for public goods is in general not optimal from a global welfare point of view. A realistic framework for viewing the policy issues is presumably one where there is a limited degree of international redistribution, so that the consumption constraints (7) and (11) must be seen as polar cases of redistributive feasibility. We begin by discussing the case (7), in which global production efficiency is a desirable feature of the global optimum.

The procedures used in practice to ensure that one produces at the cost-minimizing level, vary with the nature of the public good and the extent to which private incentives can be harnessed for this purpose. Many governments have formal guidelines for the selection of the most efficient producers, and units in charge of public procurement are subject to surveillance and possible sanctions if gross deviations from the guidelines are discovered. Competition between private firms for government contracts is in itself a powerful system for promoting production efficiency. In the area of environmental policy governments in many countries are demonstrating an increased interest in incentive systems that have long been analyzed by economists. These include Pigouvian taxes and transferable quotas.

Suppose that the national government wishes to reduce the emissions of some pollutant into the air, water or soil. One way in which this can be done in an efficient manner is to levy a tax on emissions at a uniform rate for all polluters. Every polluter then has an incentive to reduce his emissions as long as the cost of doing so is less than the tax, so that cost minimization leads to equality between the tax rate and the marginal cost of pollution reduction. This ensures that pollution will be reduced most where the reductions are cheapest, and that in equilibrium the marginal cost of reducing emissions is the same for all polluters. An alternative is to introduce a system of transferable quotas. The aggregate volume of quotas should correspond to the target level of emissions. Suppose that the government first distributes the quotas among polluters according to some more or less arbitrary criterion, e.g. past levels of pollution. Then it allows trade in quotas. Firms with high costs of reducing pollution would then wish to increase their quotas, while those with low costs would be interested in selling off some of theirs. A competitive market would establish a uniform price for quotas, and again the marginal cost of reducing pollution - or creating a less polluted environment - would be the same for all polluters.¹²

¹² For an examination of the validity of these results to the case of imperfect compliance on the part of polluters, see Sandmo (2002).

Now consider the implementation of similar policy regimes in an international setting.

In the environmental area much attention has been given to this problem in connection with the emission of greenhouse gases, e.g. CO₂. An internationally uniform tax on CO₂ would then ensure global production efficiency, while a system of international trade in emission quotas would similarly result in the largest reductions of emissions being made in the countries where it is cheapest to do so. Under either of these policy regimes, therefore, there will be one single marginal rate of transformation - one marginal cost of producing the public good - for the world as a whole. The global public good of a cleaner environment will have been achieved at the minimum cost.

This solution is optimal only when there is perfect international redistribution of income. If that is not the case, one would like the marginal cost of contributing to the global public good to be less in the poor country than in the rich. But in the case of international green taxation, this can only be achieved if the poor country has a lower tax rate than the rich. Similarly, with tradable quotas, the price of a quota must be lower in the poor country. The desire for global production efficiency must be tempered by considerations of equity. Such a modified system must be based on national tax policies or by national markets for tradable quotas. This solution should be supplemented by international treaties in order to ensure a reasonable international trade-off between efficiency and equity. How large should the difference in tax levels between rich and poor countries be? How should national quotas be set?

A possible objection to such a system is that polluting industries would have an incentive to relocate from the rich to the poor world in order to avoid high taxes or expensive quotas. But it should be noted that, as the model has been formulated, such a relocation would not in itself lead to more pollution in the poor country, since - by assumption - pollution is global and its source does not matter. Moreover, such relocation might increase the poor country's capacity for producing private goods and contribute to an increase in private standards of living. On equity grounds, therefore, the objection is not very convincing. Moreover, to the extent that the relocation were to contribute to the economic development of the poor country, the case for more favourable treatment on equity grounds would gradually become weaker, tax rates or quota prices would become more similar, and the incentives to relocate would diminish¹³.

¹³ In a more realistic setting, where pollution is not entirely of a global nature, the location of industry is likely to have additional consequences for the national environment, and the above argument would have to be modified.

Tradable quotas for greenhouse gas emissions afford perhaps the most direct example of how economic institutions can be designed with a view towards global production efficiency. In other cases, like the prevention of global epidemic diseases or the design of peace-keeping organizations, it is much less obvious that similar market institutions could be made to work. But at least the principles of production efficiency are there to guide our thinking in such areas. The international allocation of public goods production should be allocated among countries so as to minimize the global opportunity cost, although modified by distributional considerations. Whether the principle should be pursued all the way to ensure full global production efficiency, depends on the opportunities that exist for international redistribution of income via income transfers from rich to poor countries.

7. Problems of implementation: The evaluation and revelation of benefits.

In the formulation of the global welfare maximization problem in Section 5 perhaps the most strikingly utopian feature of the analysis is contained in equation (7), or, rather, in the absence of any further constraints on the division of the world's output between rich and poor. That the distribution of the world's consumption among rich and poor countries is only constrained by the world's total output is equivalent to the assumption in a national setting that the government can levy individualized lump sum taxes. Here it implies that lump sum transfers can also be used for international redistribution, and it is this assumption that allows the perfect division between equity and efficiency concerns in the optimality conditions (8)-(10). The assumption is clearly unrealistic even in a national setting. The problem is that governments do not have - indeed cannot possibly have - the information needed to implement such a tax system. Instead it must employ taxes that are distortionary and create a need to trade off efficiency losses against equity gains. In the evaluation of public goods benefits, it can no longer be assumed that total welfare benefits can be measured simply by willingness to pay or the marginal rate of substitution. Welfare weights need to be introduced in order to balance the inequities of the distribution of resources between individuals. These inequities will in general be present both within and between countries. However, in the following we shall, as in the analytical model above, ignore this problem at the national level and concentrate on the constraints on international redistribution.

Suppose that the governments of each country have found a way to estimate national benefits from global public goods. This means that they have overcome the difficulties that stem from individuals' private incentives to misrepresent their benefits in order to avoid paying for public goods¹⁴. The next step is now to arrive at a measure of global benefits from public goods. If we envisage the governments of the world negotiating about an environmental treaty, each of them finds itself in a situation which in terms of strategic considerations is similar to that of a single individual with respect to the national government. Within the international community of nations each country is small compared to the world as a whole. By underreporting its aggregate willingness to pay it may conceivably reduce the amount that it will actually have to contribute to the global public good without influencing the global provision of such goods appreciably. But if all countries reason along similar lines, the result will be under-provision of global public goods.

How serious is this international free rider problem? Again a crucial consideration is the availability of policy instruments for international redistribution. Consider first the condition (9') for optimal provision with unrestricted international transfers. If this condition is not satisfied, it is in principle possible to improve the situation for all countries through a combination of public goods adjustment and international transfers. One could envisage a system of international bargaining that would make it possible to convert a situation characterized by *potential* Pareto improvement to one of *actual* improvement, provided that the transfer mechanism were sufficiently fine-tuned and flexible. This would not eliminate the incentive problems; individual countries might still find it in their own interest to report high costs and low benefits in order to increase their net gains from international transfers. Still, the combination of contributions to global public goods provision and income transfers would increase the possibility of achieving a global optimum, compared to the case with no transfers.

The latter case can be understood by considering condition (12), which generalizes easily to an arbitrary number of countries. In the absence of international transfers the marginal benefit-cost ratios should sum to unity. But this means that at the optimum each individual country's ratio must be less than one. In other words, since a part of the benefits generated by the country in question accrue to other countries, each country will be asked to contribute

¹⁴ For surveys of methods of benefits assessment see Cropper and Oates (1992) or Sandmo (2000, ch. 4).

beyond the point where its marginal benefit-cost ratio equals one. Suppose that each country considers only its own welfare. If marginal benefit-cost ratios decline with the amount of public goods available, which is a reasonable assumption¹⁵, no country would voluntarily use resources for global public goods beyond the point where its *national* benefit-cost ratio equals unity, but this would imply that the sum of these ratios would be of the order of the number of countries in the world, indicating a severe under-provision of global public goods.

We must conclude, therefore, that whatever the difficulties are of achieving efficient and equitable provision of global public goods in combination with international transfers of income, the difficulties become magnified in the absence of such transfers¹⁶.

Some modifications may be in order. The assumption that economic agents always take a narrow view of their own self-interest when considering the allocation of resources to public goods is not totally realistic. Even for single individuals in large economies we observe that people voluntarily donate time and money for the purpose of providing public goods. The increased concern for the environment in public policy has to a large extent been influenced by voluntary organizations that have been acting as pressure groups. Many individuals, obviously, do not see themselves as unable to influence aggregate outcomes like the allocation of resources to public goods or the design of policies to modify the effects of unregulated private actions. What is true for the single individual in the national economy is also likely to be true for a single country in the community of nations, particularly so since a number of countries are actually quite big relative to the world as a whole. One might therefore expect that, at least to some extent, they might be able to internalize the effects of their own actions on the state of the global environment¹⁷.

8. Concluding remarks.

This paper has shown how the theory of pure public goods can be generalized to an international setting where countries contribute to the provision of global public goods. At

¹⁵ This follows if marginal benefits decline and marginal costs increase with the level of provision.

¹⁶ The combination of anti-pollution measures with international transfers has been discussed in a number of contributions to the literature on transfrontier pollution. For a theoretical analysis see e.g. Chander and Tulkens (1992). Mäler (1991) discusses the problem of practical implementation with numerical illustrations for the case of sulphur emissions in Europe.

¹⁷ For a more detailed discussion of the incentive structures for global public goods provision, see the article by Barrett in this volume as well as Barrett (2001).

one level of discourse, the generalization is straightforward. Under the assumption of global welfare maximization the Samuelson optimality rule remains valid for global public goods: The sum of individuals' marginal benefits, or marginal willingness to pay, should equal the marginal cost of production, which should be the same in all countries. Equivalently, the marginal benefit-cost ratio should equal unity. The measure of global marginal benefits should be the sum of the sums of individual benefits for each country in the world. However, some of the assumptions required for the result to hold are distinctly less attractive in an international setting than is the case in the context of the nation state. The crucial one among these is the availability of individualized lump sum transfers. The political feasibility of such transfers is hardly a realistic option even within the context of the nation state, and in an international context it is even more doubtful. Nevertheless, the result is interesting in showing the precise conditions under which the standard optimality conditions are valid in an international context.

In order to demonstrate the crucial role of international transfers, we have assumed that, as an alternative, lump sum transfers are indeed feasible *within* the nation state, but that they are non-existent *between* states. In that case the optimality conditions are altered. First, global production efficiency is no longer desirable; in the interests of equity, poor countries might not be required to contribute as much to global public goods as their comparative advantage would otherwise call for. Second, the optimality condition for public goods provision changes to the requirement that the sum of the national marginal benefit-cost ratios should be equal to one. This condition brings to light an important incentive problem for the global economy, since each nation state finds itself in a strategic situation similar to that of the single individual in the nation state. To ensure the maximal gain to the world as a whole, each country must contribute to a point which, at least at the margin, involves a loss to itself.

The two model alternatives - unrestricted lump sum transfers versus no transfers at all - are obviously theoretical polar cases of international income redistribution. The more general conclusion that can be drawn from the analysis is that the incentive problem is easier to overcome when decisions concerning global public goods are combined with a policy of international transfers. Indeed, in the context of rich and poor countries, a policy whereby efficiency calls for extensive provision of global public goods by poor countries (e.g. preservation of the rain forest or of tropical bio-diversity) would be easier to implement if combined with a policy of redistribution. The transfers could in principle be designed in such

a way that the overall gains from the provision of global public goods could be distributed among countries to ensure a positive gain for all.

An interesting perspective on transfers of this kind is to see them as payments for services rendered to the rich countries. The rich countries derive benefits from the poor countries' provision of global public goods, and if the poor countries do in fact have a comparative advantage in the production of such goods, the rich countries can 'buy' those goods cheaper abroad than at home. Thus, there are possible gains from trade here, but it must be kept in mind that to realize the gains one must somehow overcome the incentive problems that are inherent and inescapable in all problems of public goods allocation. Rich countries can obtain more worldwide bio-diversity - presumably a global public good - by paying poor countries to spend more resources on protecting endangered species. But a single rich country is nevertheless exposed to free rider incentives to let other rich countries foot the bill.

For transfers of income to play the role envisaged here, they must be designed in a way that is rather different from current systems of foreign aid. Economists have sometimes argued in favour of non-conditional aid as the best way to overcome international inequality, and this would be consistent with the implications of the first version of our theoretical model. But in the context of a more restricted and practical role for income transfers, they ought rather to be designed so as to make them conditional on contributions to the provision of global public goods.

The main difference between public goods provision in the nation state and the global economy lies in the link with tax payments. Two differences of principle are of crucial importance. The first is that, in the nation state, a tax-financed increase in public goods could pass the benefit-cost test without providing gains to each and every citizen. This is because the nation state has instruments of enforcement by which it can extract payments also from those citizens who are not net beneficiaries from the policy, while the world community of sovereign nations do not possess policy instruments of this kind. In the global community participation in the policy must therefore be based on voluntary participation, so that it becomes important to develop policy tools that distribute the gains to all participating nations. The second difference lies in the possibilities of developing credible systems of enforcement. Even when all countries gain from the policies, individual countries would have an incentive to engage in various activities - such as misrepresentation of benefits or costs, evasion or

avoidance of taxes or quotas - that would increase their net share of the global gains further. A viable system of global public goods provision must to some extent be based on countries' acceptance of a notion of global welfare that goes beyond national self-interest.

Appendix: The derivation of equation (12).

Consider the problem of maximizing the welfare function (2), subject to the constraints (3'), (4') and (11). The Lagrange function can be written as

$$\begin{aligned} L = & W(u^{1R}, \dots, u^{nR}; u^{1P}, \dots, u^{mP}) - \mathbf{1}(g - g^R - g^P) - \mathbf{m}^R[x^R + C^R(g^R) - R^R] - \mathbf{m}^P[x^P + C^P(g^P) - R^P] \\ & - \mathbf{g}^R(\mathbf{S}_i x^{iR} - x^R) - \mathbf{g}^P(\mathbf{S}_j x^{jP} - x^P). \end{aligned} \quad (\text{A1})$$

The first order conditions for a maximum are

$$\mathbb{J}L/\mathbb{J}x^{iR} = W_{iR}u^{iR}_x - \mathbf{g}^R = 0. \quad (i=1, \dots, n) \quad (\text{A2})$$

$$\mathbb{J}L/\mathbb{J}x^{jP} = W_{jP}u^{jP}_x - \mathbf{g}^P = 0. \quad (j=1, \dots, m) \quad (\text{A3})$$

$$\mathbb{J}L/g = \mathbf{S}_i W_{iR}u^{iR}_g + \mathbf{S}_j W_{jP}u^{jP}_g - \mathbf{1} = 0. \quad (\text{A4})$$

$$\mathbb{J}L/g^R = \mathbf{1} - \mathbf{m}^R C^R_g = 0. \quad (\text{A5})$$

$$\mathbb{J}L/g^P = \mathbf{1} - \mathbf{m}^P C^P_g = 0. \quad (\text{A6})$$

$$\mathbb{J}L/x^R = -\mathbf{m}^R + \mathbf{g}^R = 0. \quad (\text{A7})$$

$$\mathbb{J}L/x^P = -\mathbf{m}^P + \mathbf{g}^P = 0. \quad (\text{A8})$$

Substituting from (A2) and (A3) into (A4), we obtain

$$\mathbf{S}_i (u^{iR}_g / u^{iR}_x) \mathbf{g}^R + \mathbf{S}_j (u^{jP}_g / u^{jP}_x) \mathbf{g}^P = \mathbf{1}. \quad (\text{A9})$$

We now use (A5)-(A8) to find that $\mathbf{g}^R = \mathbf{1}/C^R_g$ and $\mathbf{g}^P = \mathbf{1}/C^P_g$. Dividing by these expressions in (A9) yields equation (12) in the main text. Note also that this implies that the ratio of marginal costs equals the inverse ratio of social marginal utilities of income, i.e. $\mathbf{g}^P/\mathbf{g}^R = C^R_g/C^P_g$, and this establishes the link between cost weights and welfare weights.

Now assume that instead of the two constraints (11) we have just the single constraint (7). The last two terms of the Lagrangian (A1) then collapse into one, with the single multiplier \mathbf{g} . (A9) becomes

$$\mathbf{S}_i(u_g^{iR}/u_x^{iR}) + \mathbf{S}_j(u_g^{jP}/u_x^{jP}) = \mathbf{I}/\mathbf{g} \quad (\text{A10})$$

From (A5)-(A8) it then follows that $\mathbf{I}/\mathbf{g} = C_g^R = C_g^P$. With C_g being the common value of this, we have equation (9) or (9') in the text.

References.

Arrow, Kenneth J. (1951), *Social Choice and Individual Values*. New York: Wiley. Second Edition 1963.

Barrett, Scott (2001), 'International cooperation for sale,' *European Economic Review*, 45: 1835-1850.

Bruce, Neil and Douglas D. Purvis (1985), 'The specification and influence of goods and factor markets in open-economy macroeconomic models,' R. W. Jones and P. B. Kenen (eds.), *Handbook of International Economics*, Vol. II: 807-857. Amsterdam: Elsevier Science Publishers.

Buchanan, James M. (1987), *Economics: Between Predictive Science and Moral Philosophy*. College Station: Texas A&M University Press.

Chander, Parkash and Henry Tulkens (1992), 'Theoretical foundations of negotiations and cost sharing in transfrontier pollution problems', *European Economic Review*, 36: 388-398.

Cornes, Richard and Todd Sandler (1996), *The Theory of Externalities, Public Goods, and Club Goods*, Second Edition. Cambridge: Cambridge University Press.

Cropper, M. L. and W. E. Oates (1992), 'Environmental economics: A survey', *Journal of Economic Literature*, 30: 675-740.

Diamond, Peter A. and James A. Mirrlees (1971), 'Optimal taxation and public production I-II', *American Economic Review*, 61: 8-27 and 261-78.

Kaul, Inge, Grunberg, Isabelle and Stern, Marc A. (1999), *Global Public Goods: International Cooperation in the 21st Century*. Oxford: Oxford University Press.

Mäler, Karl-Göran (1991), 'Environmental issues in the new Europe', Anthony B. Atkinson and Renato Brunetta (eds.), *Economics for the New Europe*. London: Macmillan, in association with the International Economic Association.

Oakland, William H. (1987), 'Theory of public goods,' A. J. Auerbach and M. Feldstein (eds.), *Handbook of Public Economics*, Vol. II: 485-535. Amsterdam: Elsevier Science Publishers.

Samuelson, Paul A. (1954), 'The pure theory of public expenditure', *Review of Economics and Statistics*, 36: 387-9.

Samuelson, Paul A. (1955), 'Diagrammatic exposition of a theory of public expenditure', *Review of Economics and Statistics*, 37: 350-6.

Sandmo, Agnar (1987), 'Public goods,' *The New Palgrave*, Vol. 3: 1061-1066. London: Macmillan.

Sandmo, Agnar (2000), *The Public Economics of the Environment*. Oxford: Oxford University Press.

Sandmo, Agnar (2002), 'Efficient environmental policy with imperfect compliance', *Environmental and Resource Economics*, forthcoming.